Improvement of Time Comparison Results by using GPS Dual Frequency Codeless Receivers Measuring Ionospheric Delay

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ABSTRACT

A dual frequency GPS receiver measuring ionospheric delay or TEC (Total Electron Content) named GTR-2 was constructed in BIPM (Bureau International des Poids et Mesures)[1], and operates in regular base since October 1988. CRL (Communications Research Laboratory) also has completed a development of the same equipment this year. It has almost same performances as GTR-2 in BIPM. By using these two receivers, we have begun to compensate the time transfer results obtained from the conventional GPS time transfer receivers between Japan and Europe under the cooperation of CRL and BIPM for a construction of a tight time-transfer link by using GPS satellite. This paper shows the improvement of GPS time transfer results by using the ionospheric delays measured by GTR-2.

For a highly transportable geodetic purpose VLBI (Very Long Baseline Interferometer) station, CRL has another application program of GTR-2. For this compact VLBI station, we are making a study of ionospheric compensation of the signal from radio stars by using the TEC data obtained from GTR-2.

CRL also have a plan of an improved version of GTR-2 which uses the phase informations of reconstructed continuous signals obtained by making cross correlation of the received L1(1575.42 MHz) and L2(1227.6 MHz) signals from the GPS satellites. By using this method, it can be estimated that this equipment can make more than one order of precise measurement of the TEC than GTR-2.

INTRODUCTION

The ionospheric delay is one of the largest sources of error for the time comparison and the positioning by using GPS satellites. The activity of the ionosphere depends largely on solar activity which has a long term cycle of about 11 years. The solar activity will be maximum around 1991, the effects of the ionosphere will be very large in coming few years. And as this solar maximum is estimated as a one of the largest one, then it is expected that the ionospheric activity will have large effects not only on the time comparison and the positioning but also on the communication links via communication satellites.

MEASUREMENTS RESULTS OF TEC BY GTR-2

The construction of GTR-2 in CRL has completed in the beginning of May,

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1989, and we started its continuous operation since that time. It uses a directional antenna which has a gain of about 10 dBi for L1 and L2 signals of GPS satellite. It has a measurement precision of about 2×10^{16} electrons/m^2 of TEC and about 1 ns of L1 signal group delay.

Figure 1 shows the measurement results of TEC for July, 1989 obtained by the GTR-2 in CRL. This figure shows the estimated vertical TEC from the measured TEC along the line of sight to the GPS satellites by using a simple ionosphere model. From this figure L1 signal has more the 10 ns of daily variation caused by the ionosphere. Therefore it can be said that one must make ionospheic compensation by using actual ionospheric delay to perform a precise time comparison or positioning.

APPLICATION TO TIME COMPARISON RESULTS

The major time keeping laboratories make the daily time comparison by using GPS time transfer receivers under the common view[2] schedule calculated by BIPM. They use the conventional GPS time transfer receivers which receive the L1 C/A code signal of the GPS satellites, and they make ionospheric delay correction by the ionospheric delay model transmitted from GPS satellites. This ionospheric correction model[3] is very useful for the single frequency GPS users, but it has not enough precision to make a precise time comparison or positioning.

Between OP (Paris Observatory) and CRL, we made the ionospheric delay correction by the ionospheric delays measured by GTR-2 on both sites instead of the correction model. Figure 2 shows its shematic concept. GTR-2 on both sites are programmed to make simultaneous measurements with time transfer receivers.

Under the common-view time transfer schedule No.13 calculated by BIPM, we have 8 common-view tracks for each day between Japan and Europe. Figure 3 shows the time comparison results for three months between OP and CRL. In this figure two curves are plotted, one is UTC(OP)-UTC(CRL) by using raw data obtained from commercial GPS time transfer receivers which use the ionospheric correction model and the other is UTC(OP)-UTC(CRL) corrected by the ionospheric delay measured by GTR-2 on both sites, and 100 ns of offset are given to divide them. Figure 4 shows the zoomed plots of the time comparison results of figure 3 (11 days of the beginning of July), and we can see that the time comparison is performed with much higher precision when the measured ionospheric delays are involved.

APPLICATION TO SINGLE FREQUENCY VLBI OBSERVATION

For the geodetical application of GTR-2, CRL is planning to apply GTR-2 to VLBI experiments.

In order to realize a compact and high cost-performance system, a highly transportable VLBI station with 3m antenna is now under development in CRL[4]. For the conventional geodetic VLBI experiments, each VLBI station makes the obserbations by dual frequency (X-band and S-band) to compensate the relative ionospheric delay between both sites. Therefore each station should be equipped the facilities for these two receiving bands, such as feeds, low noise amplifiers, local signals, backend equipments and so on.

On the other hand, if one can estimate the ionospheric delay by using other method, each VLBI station has no need to make the dual frequency measurement. This means that the one can realize the maximum antenna efficiency for the X-band which is the main frequency band for the geodetic VLBI measurement, and can

reduce the VLBI facilities. These merits are very effective for small mobile VLBI stations.

For this purpose we are planing single frequency VLBI experiments by using our highly transportable VLBI station and GTR-2. The key subject in this experiment is how to estimate the ionospheric delay of the line of sight to the radio stars from that of the GPS satellite. To study this subject we are making simultaneous observations of the normal two frequency VLBI experiments and GTR-2 observation. The shematic concept is denoted in figure 5.

MORE PRECISE MEASUREMENT

As the GTR-2 uses a technique of the amplitude measurement of the cross-correlated signal between received L1 and L2 P-code of the GPS satellite, then the measurement precision of TEC is limited by the S/N ratio of the received signals and the period of the P-code clock rate (about 100 ns). Namely the precision is proportional to the period of signal and square-root of inverse of S/N ratio. Therefore, to make precise measurement of TEC, we should use a high gain antenna to increase S/N ratio or a long integration time to increase the number of samples.

For the other solution to improve the measurement precision, we are planning a more precise device, named GTR-3, which uses the phase measurement technique of the reconstructed continuous signals which have the frequency of L1-L2 and L1+L2. By using this method, we can use the period of about 2.8 ns (for L1-L2 signal) and about 0.36 ns (for L1+L2 signal). By using this method we can improve the measurement precision of TEC by more then one order compared to the GTR-2 method. In this method we should use the coherent local signals in the receiver for the signal processing to keep the phase informations. Figure 6 shows the block diagram of this receiver.

Normally, the ambiguity of period of the measurement signal is one of the largest problems to be solved, but the method mentioned above has an advantage for this problem compared to other methods. The detailed discussion will be made in the other occasion.

CONCLUSION

Using GTR-2 on both sites of time comparison stations, the improvement of the precision of time comparison were obtained. In the case of long distance time comparison between OP and CRL, we can get the rms variation of less than 10 ns by using the ionospheric delay obtained by GTR-2. This experiment is continuously made under the cooperation between CRL and BIPM. As GTR-2 has a simple structure and easily make a TEC measurement, then it can use in wide domains of science and technology not only in time comparison or geodesy.

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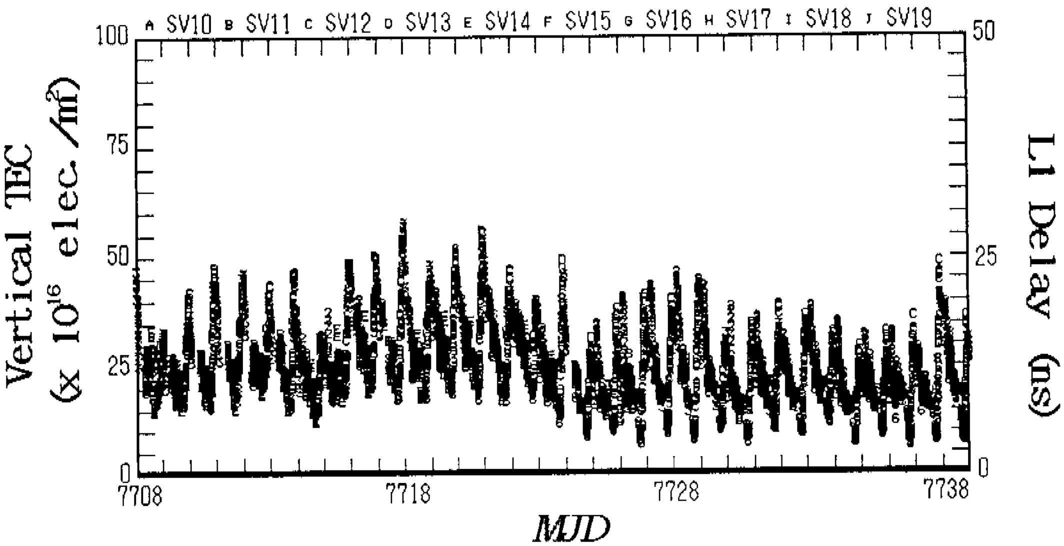
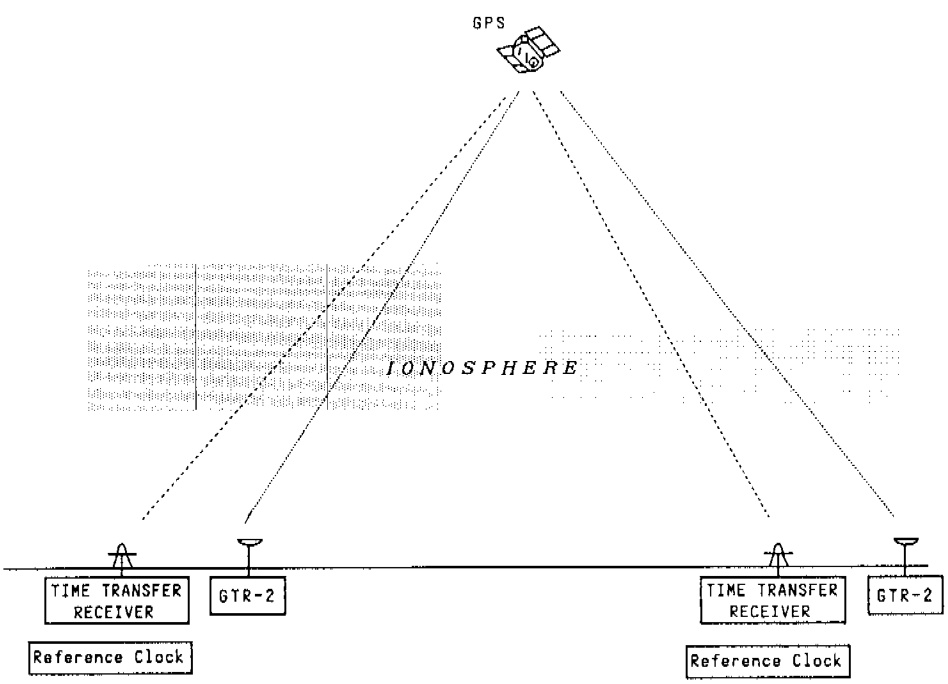
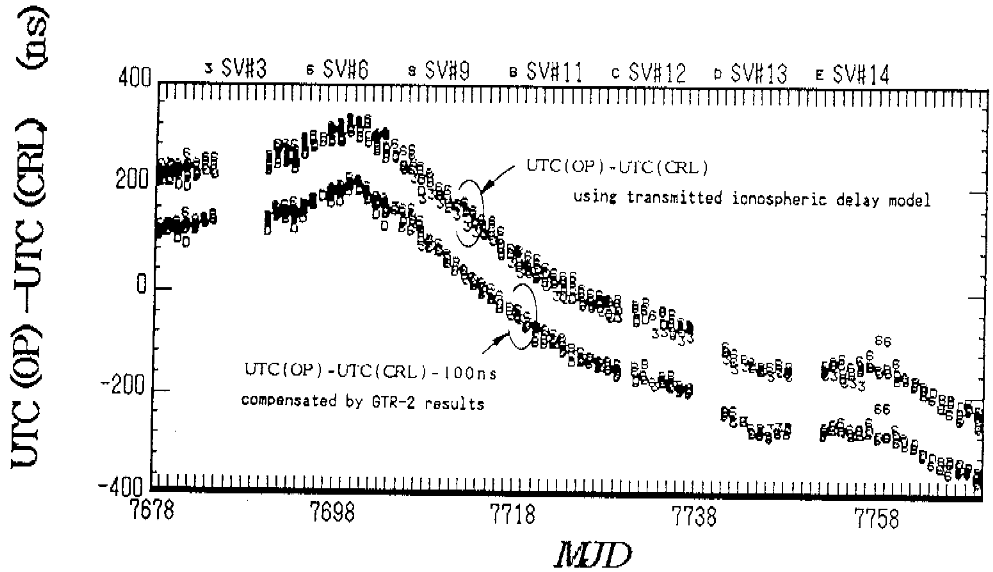


Measurement Results of TEC by GTR-2
(July 1989 measured from CRL)

Figure 1

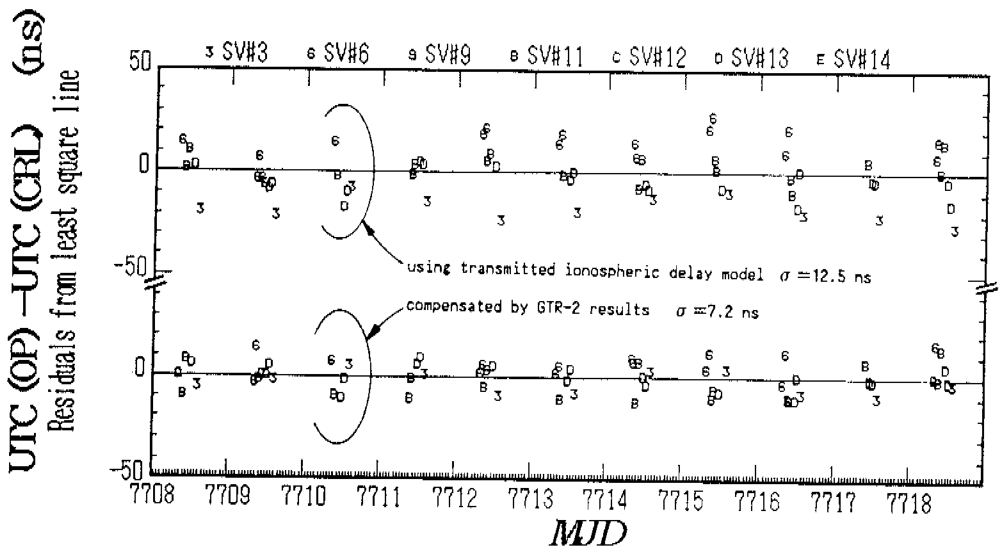


Application to Time Transfer
Figure 2



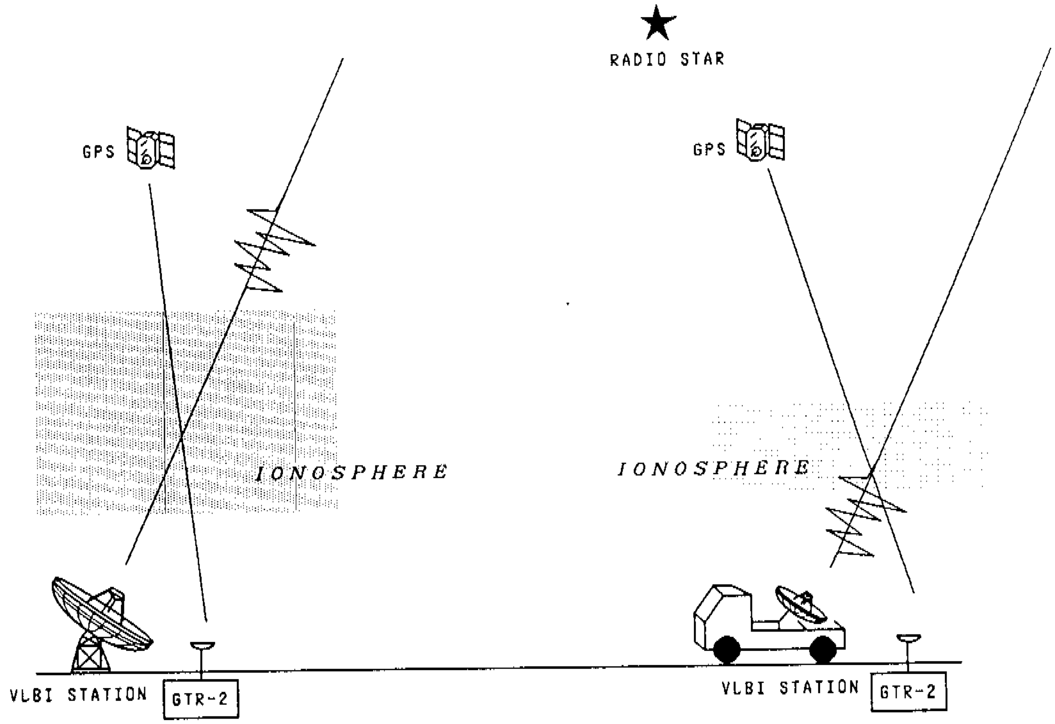
Application results of measured TEC to the time comparison results between OP and CRL (June~August, 1989)

Figure 3



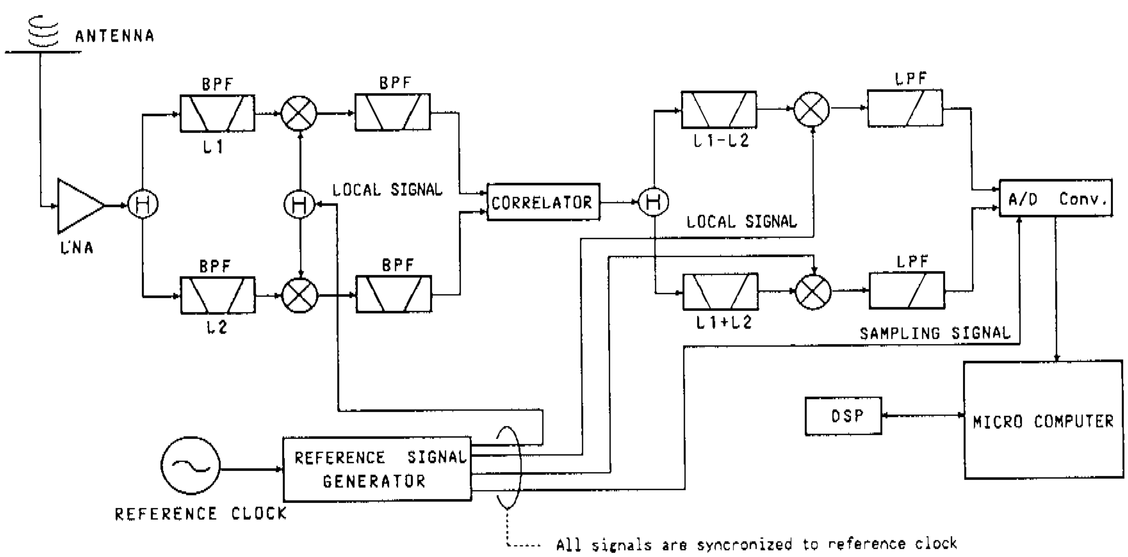
Application results of measured TEC to the time comparison results between OP and CRL (July 1st ~ July 11, 1989)

Figure 4



Application to single frequency VLBI observation

Figure 5



Block diagram of high-precision TEC reciver plan (GTR-3) (using reconstructed continuous signal phases by cross-correlation)

Figure 6